



# **Human Centered Systems**

**Michael Shafto**

**Barbara Brown**

**AAAI-02 / IAAI-02 Tutorial Forum**

**AI in Space: Unique Challenges and Opportunities**

**Dan Clancy, Organizer**

**Edmonton, Alberta, Canada**

**July 28, 2002**

This presentation provides an overview of the Human Centered Systems R&D being supported by NASA's Computing, Information & Communications Technology Program. Mike Shafto is the Manager of HCS, and Barbara Brown is the Deputy Manager.

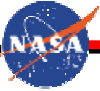


# Outline

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- **Motivation**
- **Strategic Approach**
- **Selected Projects and Products**
  - **Multimodal Interface Technology**
    - Collaborative Science
    - Dialogue Systems
    - Products
  - **Human-System Modeling**
    - Brahms
    - Apex-GOMS
    - Products
  - **Agent-Based Decision Systems**
    - Mars Exploration Rovers HCS Tasks
    - Intelligent Launch and Range Operations
    - Integrated Mission Operations for ISS
- **Opportunities**

# NASA Missions



Human Centered Systems R&D develops, demonstrates, and tests technology options to address NASA requirements for advanced mission systems. Most of the work is directed toward NASA's primary missions in space exploration. This work includes launch and range operations, vehicle processing, Space Transportation System (STS) and International Space Station (ISS) operations, ground operations, and remote operations in such Space Science missions as the Mars Exploration Rovers (MER) and Mars Smart Lander (MSL) missions.

We also develop technology options for the enhancement of aviation safety and security, and for advanced air-ground integration in civil aviation.



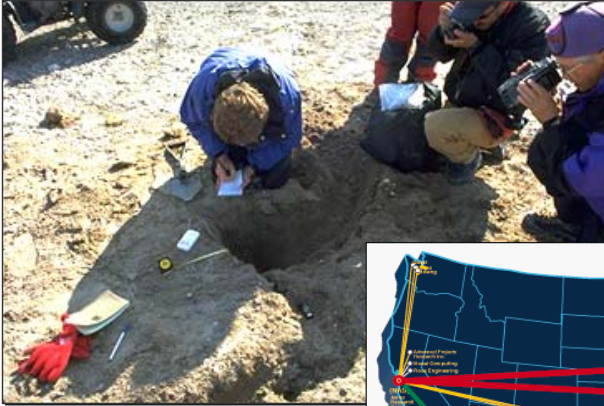
## Teamwork in NASA Today



NASA's work is fundamentally team-oriented. Today's operations in mission control, payload integration, vehicle processing, and remote exploration are conducted by large, co-located teams of highly experienced experts. The success of NASA's missions depends entirely on the experience and knowledge of these teams of experts.

Due to the important role of tacit knowledge and on-the-job training, this mode of operations will be impossible to maintain in the future. Already "24-7" operations, such as launch and range operations at Kennedy Space Center (KSC) and International Space Station mission operations at Johnson Space Center (JSC), have raised significant issues with regard to sustainability. Technical and economic challenges, as well as the changing nature of NASA's mission portfolio, make it necessary to envision and to plan for a different operational mode in the future.

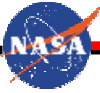
# Future NASA Teams



In the future, NASA teams will be smaller and more isolated, as illustrated here by a small team of scientists working at the Flashline Mars Arctic Research Station (FMARS) field site.

Teams will also be larger and more distributed, as represented here by a widely distributed, heterogeneous design team collaborating by means of an intelligent networked infrastructure (DARWIN).

HCS research is developing the technology base to understand and to meet the requirements of these future NASA teams.

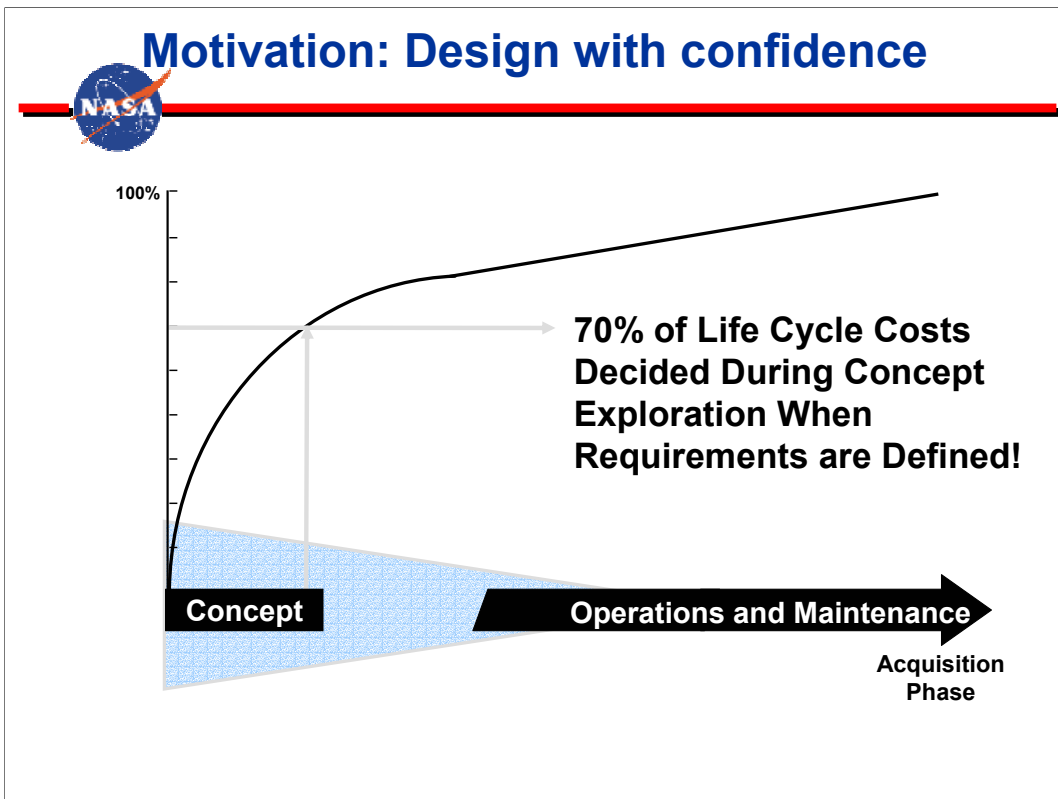


## NASA's HCS Challenges

- **Design of Mission Systems**
- **Remote Science Planning and Operations**
- **Mission-Critical, Real-Time Operations**
- **Multi-Mission Knowledge Management**
- **Cross-Cutting Trends**
  - Smaller local teams, larger distributed teams
  - More complex missions
  - Mixed-initiative autonomous systems
  - Dynamic, heterogeneous knowledge bases
  - *Increasing demands on individual decision makers*
  - *Need to design and plan with confidence*

Code M (Office of Space Flight), Code S (Office of Space Science), and Code R (Office of Aerospace Technology) face similar challenges related to the design and deployment of unique, complex mission systems. A mission system is defined as the experts, procedures, software and other supporting technologies required to conduct a NASA mission. In the case of Code R we extend the notion of “a NASA mission” to include, for example, the development of system-level technologies for air-ground integration and security in civil aviation.

All the mission systems of concern to HCS are characterized by the cross-cutting trends listed above.



Studies by the US Air Force and others have shown that the life-cycle costs of complex systems are largely determined by decisions made in early design phases -- when ignorance is maximal. Model-based design methods are required to envision and quantify real operational scenarios during these early design phases. Human performance models are needed to fill critical gaps in our design capabilities: Life cycle costs and risks are mitigated when human behavior can be included in early design-related models. In the absence of credible human behavior models, it is too easy to push aside complex performance and integration issues with the claim that they will be discovered and dealt with during “training.”

A type of HCS metric that applies here is planned-vs.-actual system performance, including both productivity (e.g., science return) and cost/risk metrics. One of the main goals of HCS research is to enable human-system modeling early in the design cycle, so that actual life-cycle operations and maintenance costs can be more accurately predicted.



## **Example: Increasing demands on individual decision makers**

- **Research by Dr. Jiajie Zhang & colleagues, University of Texas Houston Medical Center**
- **The Flight Surgeon (FS)**
  - The medical doctor for astronauts
  - In the flight control room
- **The Biomedical Engineer (BME)**
  - The person supporting the flight surgeon and handling and coordinating all medically related information and activities
  - The BME is a key decision maker for International Space Station mission operations

This example is due to Jiajie Zhang and his colleagues at the University of Texas Houston Medical Center and at NASA-JSC. They analyzed in detail the workload and work practices of Biomedical Engineers (BME's), who play key decision-making roles in mission operations for the International Space Station (ISS). BME's are responsible for monitoring and proactively maintaining the environmental systems that are critical to the health and well-being of the ISS crew.



## The Planned BME Handover Procedure

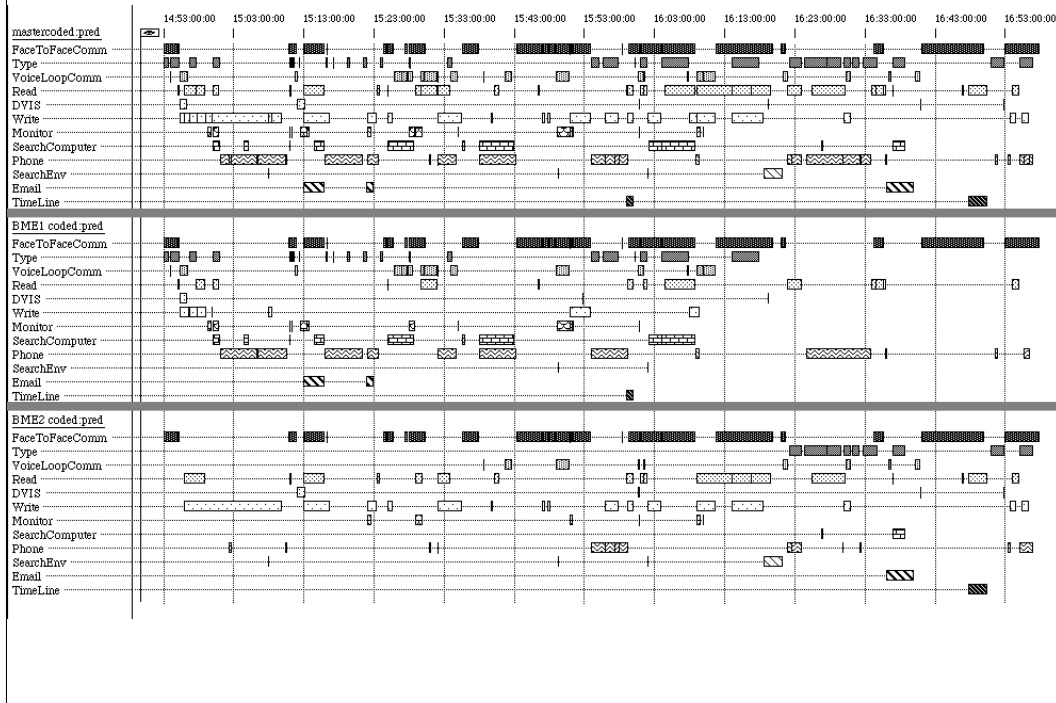
- **Standard allocated time: one hour**
  - **First half hour**
    - Between on-console and oncoming BMEs
    - Oncoming BME reads documents: handover notes, flight notes, anomaly reports, daily and weekly medical reports, ....
    - Oncoming BME asks questions for clarification, and on-console BME adds further explanation.
    - Oncoming BME reads current environmental telemetry parameters, daily timeline for changes to mission plans and status, and uplinked procedural changes.
  - **Second half hour**
    - Oncoming BME participates in the Flight Control Team (FCT) handover on the Alternate Flight Director (AFD) loop
    - On-console BME continues to monitor normal flight loops and keeps the oncoming BME informed of any pertinent activities
    - Once the FCT handover is complete, the oncoming BME has the opportunity to ask the on-console BME any questions that may have surfaced during the handover.

Like almost all NASA mission-related work practices, the BMEs' work practices are formalized in carefully planned procedures.

A key aspect of the work of BMEs and many other NASA decision makers is that the formalized procedures do not reflect all the important work that must be done. Also, the formally planned tasks cannot be performed in the time allocated under prevailing conditions of reduced staffing.

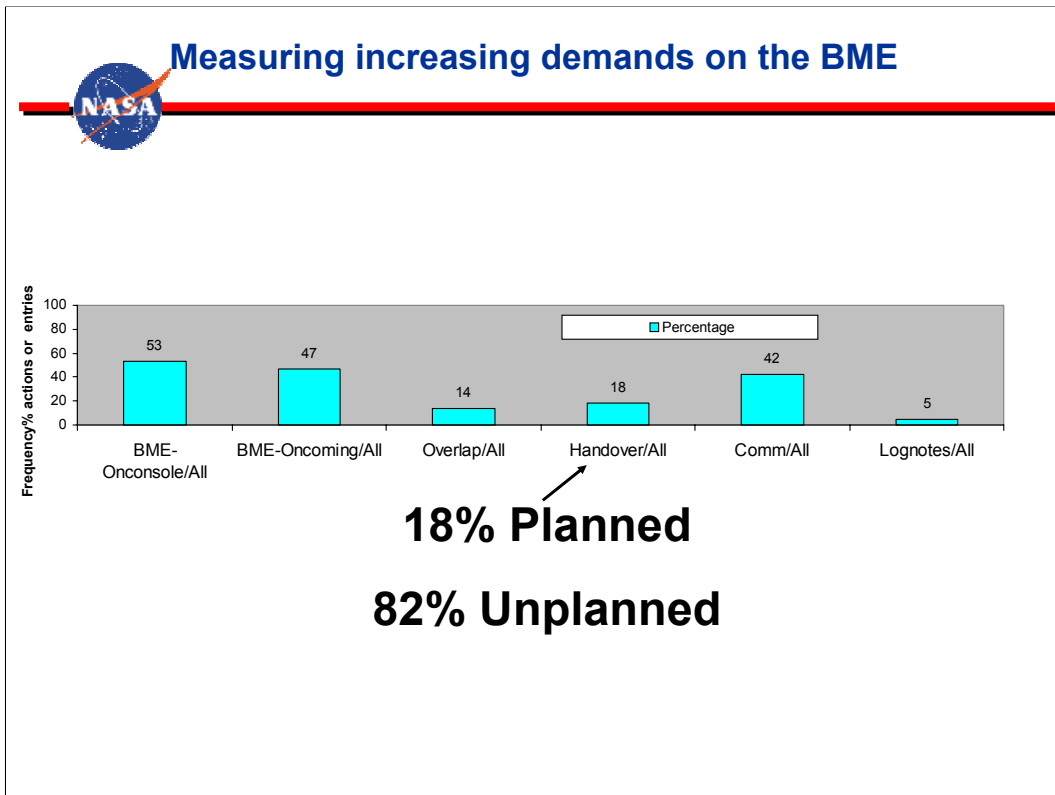
This example is important not just because of the mission-critical decision-making role of the BMEs, but also because the BME position is typical of key decision making roles at JSC, KSC, JPL, and throughout NASA. Reduced staffing levels and rapidly changing mission requirements underscore the need for mission-systems design methods that can incorporate accurate predictive models of the performance capabilities of experts like the BMEs, as well as the embedded training/aiding technologies needed to establish and maintain high levels of expertise.

## Analyzing increasing demands on the BME



Recording and visualizing the actual work practice of the BMEs, as Zhang and his colleagues have done, shows that the BME's work is characterized by many interactions, interruptions and complex dynamic constraints.

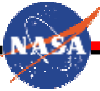
The purpose of this type of analysis is to identify specific requirements and opportunities for the insertion of advanced aiding systems, information management systems, and other innovative technologies. Besides Zhang's own work, several other HCS projects are addressing these kinds of NASA requirements across all major types of missions.



One conclusion that can be drawn from Zhang's detailed analyses and measurements is that about 18% of the tasks performed during BME shift handover correspond to the planned procedures, and the balance correspond to other required tasks outside the planned procedures.

Much of the unplanned workload has to do with information retrieval and tracking, and with managing multiple communication channels and interruptions.

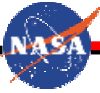
Comparison of planned to unplanned work is an excellent HCS metric, and is applicable to all major types of missions, including Shuttle and Station operations, vehicle processing, and ground operations for remote science missions. This metric can be implemented in terms of time or in terms of task-count. Time- and task-based analyses can, in principle, be related to cost and risk metrics. The relation of metrics at the individual performance level to metrics at the system level is, however, an open research issue at this time. See P.S. Goodman & D.H. Harris. (1995). Productivity in Organizations. In R.S. Nickerson (Ed.), *Emerging needs and opportunities for Human Factors research*. Washington, DC: National Academy Press, pp. 71-85.



# Outline

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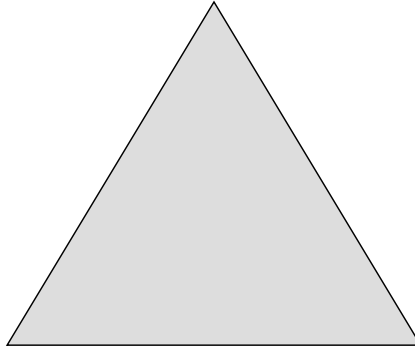
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# HCS Strategy [1]

*Integrate, Test, and  
Transfer Technology*

**Decision Systems**



**Human-System  
Modeling**

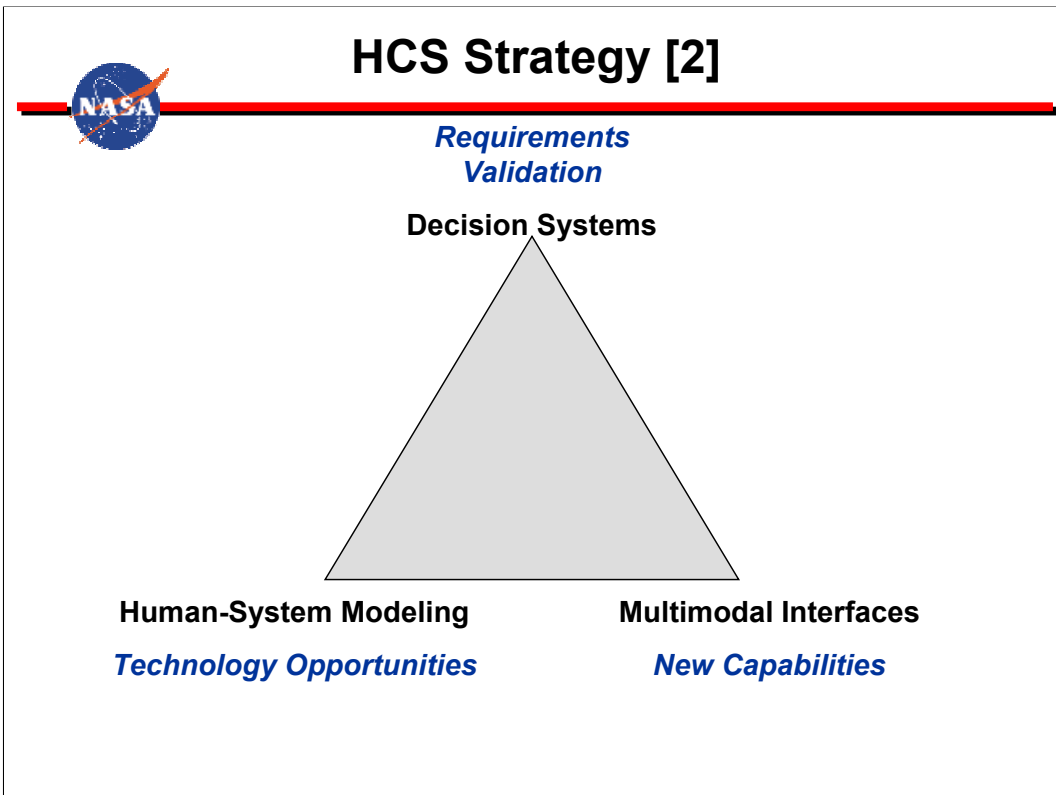
*Design with confidence*

**Multimodal Interfaces**

*Effective performance*

Human Centered Systems R&D is composed of sub-elements which aim to advance the state-of-the-art in Human-System Modeling and to extend the technology options for Multimodal Interfaces in selected areas of particular importance to NASA. The third sub-element aims to prototype innovative Decision Systems, using the component technologies being developed in the other two sub-elements.

As we discover successful approaches to building and testing complex decision systems, we should be able to avoid emergent problems like those illustrated above in the case of the BMEs. We should be able to design and implement cost-effective mission systems with predictable safety and performance properties.

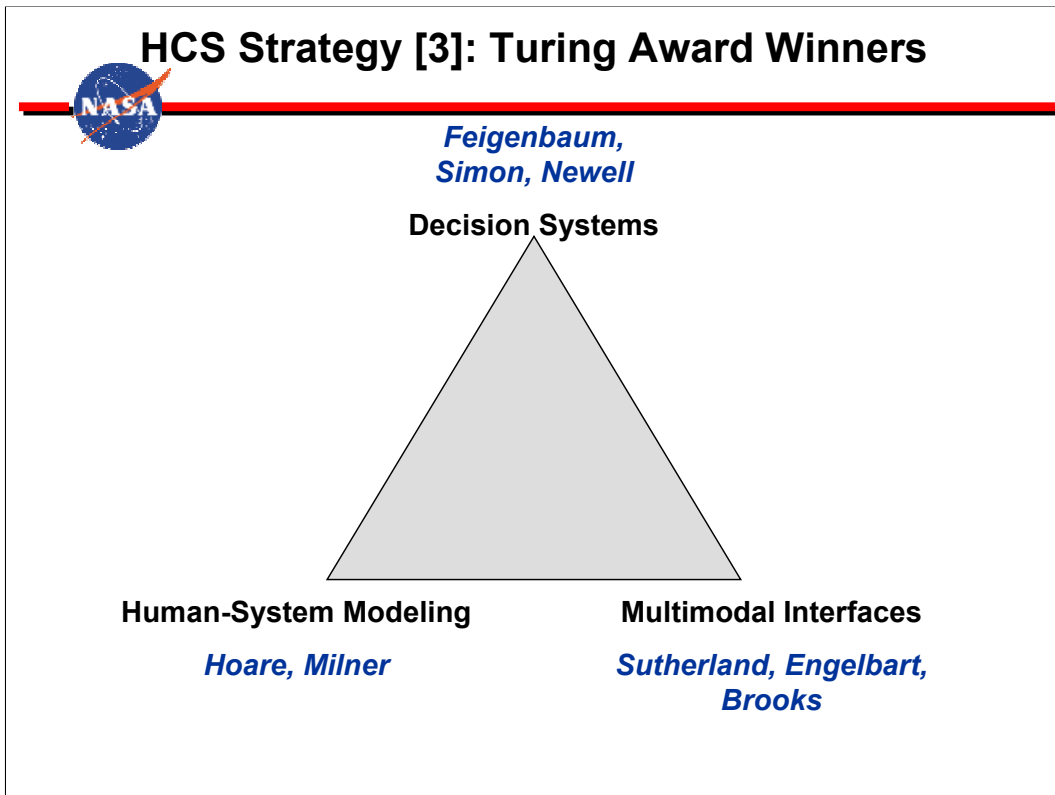


In the course of prototyping innovative Decision Systems (which is always done in close collaboration with mission experts at Centers like JPL, JSC, and KSC) it is possible to discover new requirements and to validate, refine, and prioritize known requirements.

Empirical requirements analysis – of which participatory design is just one form – is one of the fundamental methodologies that characterizes HCS as an approach to software engineering. It has the side-benefit of pre-adapting technologies to the target work environment, thus facilitating or actually accomplishing “technology transfer.”

Mission planners also become aware of new capabilities, such as dialogue systems and other natural-language technologies. Human-system modeling technologies can be applied to mission planning and procedures design, highlighting opportunities and requirements for technology insertion.

This general technical approach is well-illustrated in the case of the Mars Exploration Rovers (MER) project, Intelligent Launch and Range Operations project (ILRO), and International Space Station projects discussed later.



The triadic structure of NASA's Human Centered Systems R&D strategy reflects the intellectual roots of HCS in the work of some of the pioneers of Computer Science. Effective decision systems will require computational representations of at least some aspects of human knowledge, learning, and communication. This vision has been fundamental to the field of AI, as reflected in the work of Simon, Newell, Feigenbaum (Minsky, McCarthy, Reddy ...).

Although the work of Hoare and Milner (also Pnueli) is usually associated with software design and testing, their mathematical concepts are fundamental to thinking clearly about any kind of dynamic system that combines discrete and continuous change, delayed effects, recursion, and stochastic elements. Thus, "formal methods" are being extended to human-machine systems by a number of researchers (John Rushby, Nancy Leveson, Claire Tomlin, Lance Sherry and Peter Polson, Jeff Bradshaw, Asaf Degani, Ev Palmer, and others). In general, these mathematical approaches are more about thinking clearly than about proving theorems. They provide the right tools for developing simulation-based testing methods, even when exhaustive analysis is impractical.

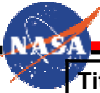
Graphical and quasi-graphical systems are probably most often associated with HCI and HCS. The radically innovative work of Engelbart, Sutherland, and Brooks has certainly redefined the digital computer as an instrument of social change. Through HCS R&D we hope to understand the best ways to use graphical, symbolic, and hybrid representations of NASA's complex vehicles and mission systems.



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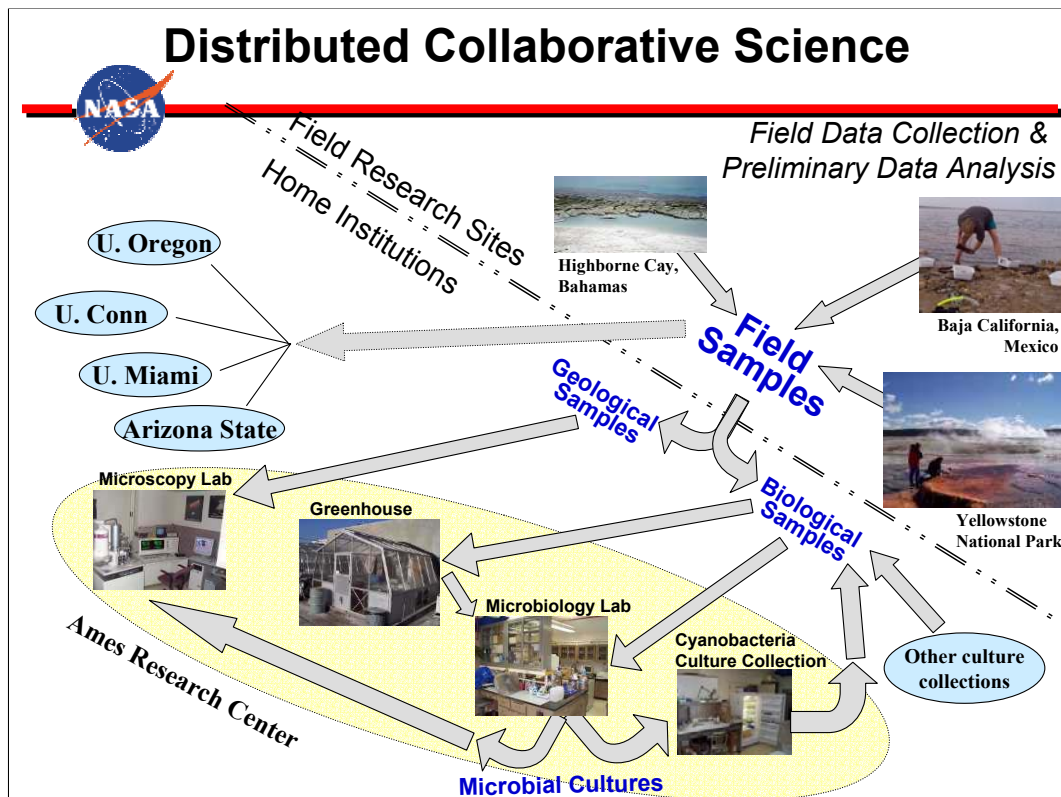
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# Multimodal Interfaces

Title	Org.	PI
Distributed Collaborative Science	ARC	Keller
Concept Maps for Mars Exploration	IHMC	Cañas
Knowledge Capture, Refinement and Sharing	Indiana	Leake
HCI for Mission-Critical Systems	JPL	Kohen
Causal Reasoning	Brown	Sloman
Filtering Information in Complex Domains	ISLE	Langley
Advanced Dialogue Systems	RIACS	Hieronymus
Speech Prosody	SRI	Shriberg
Robust Speech Recognition	USC	Berger
Biologically Based Human-Computer Interfaces	ARC	Trejo
Architectures for Multimodal Interface Design	ARC	Begault

Natural-language and language-like technologies have come to the fore, in addition to integrative graphical interface technologies designed to reflect the semantics of science and mission operations. Language-like or language-related technologies include not only speech and dialogue systems, but also concept maps and causal representations. These are being investigated as bases for innovative methods to address unique NASA requirements in the area of high-bandwidth, heterogeneous, real-time data visualization and interpretation for remote science, model-based (predictive) control, on-board system-management and procedure-execution, and information management for ground operations.



<http://sciencedesk.arc.nasa.gov/organizer/>

The ScienceOrganizer system is an information repository for distributed scientific teams. ScienceOrganizer has users affiliated with the NASA Astrobiology Institute, the Ames Exobiology Branch, and other institutions. A major new version of ScienceOrganizer was recently released to over 50 registered users. This version incorporates numerous enhancements to the user interface and other system functionality, a facility to automate the inference of relationships among items in the repository, and access-controls to protect items in the repository based on membership in groups or projects. ScienceOrganizer also permits users to organize files or documents that are not physically stored on the ScienceOrganizer server, but are stored remotely on a network-accessible http server.

ScienceOrganizer is related to other HCS projects which address requirements for knowledge management to support remote and distributed science.

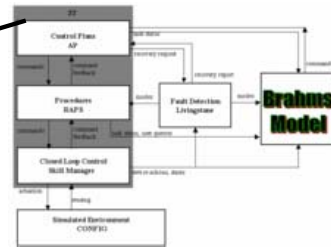
# Remote Science & Field Research



- **What conversations occur during data collection?**
- **How do on-site interpretations affect quality of data collected?**
- **How are individual records correlated?**

Remote links into a system like Science Organizer could meet some of the key requirements that have been identified in the Flashline Mars Arctic Research Station field studies. These field studies simulate some aspects of human exploration of Mars.

The automated acquisition of time- and place-stamps may enable more powerful analytical methods that can re-integrate biological, geological, meteorological, and chemical data obtained from unique field studies. NASA participates in field studies like FMARS in order to experimentally discover and validate the technology requirements for its remote science missions.



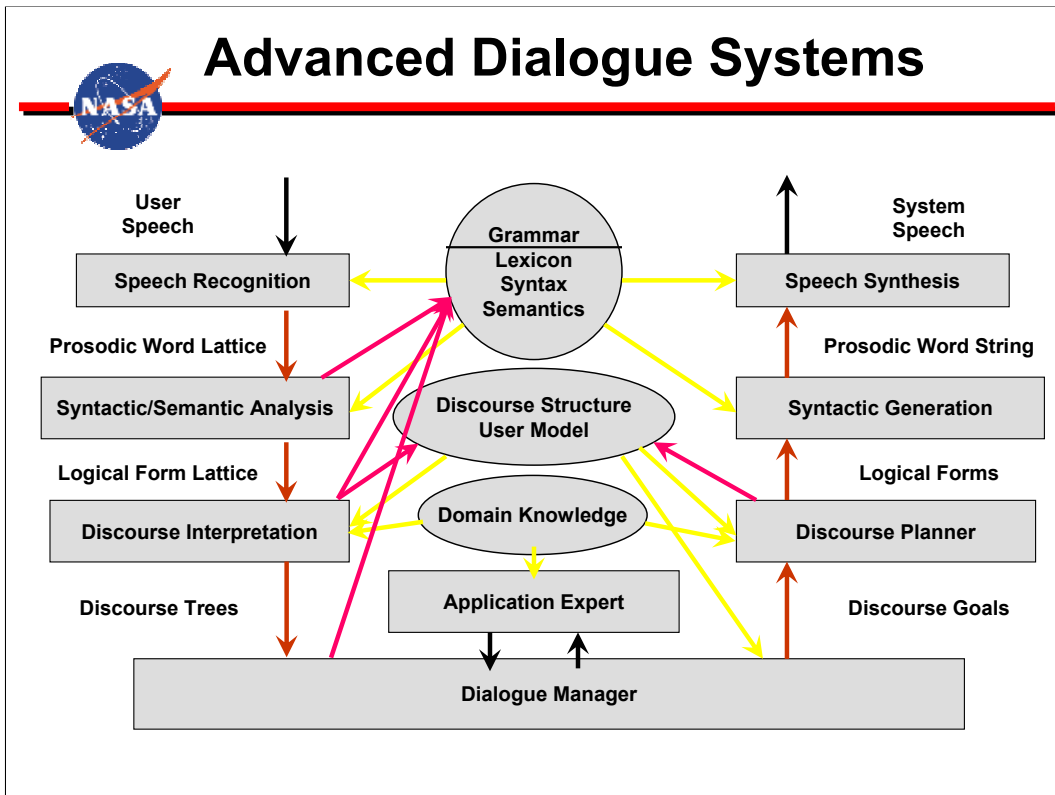
## Collaborators

## DARPA Interactive Systems

The diagram illustrates the BRAHMS Sim & Agent architecture. A central figure, labeled 'Explorers/Scientists', is connected to several components. On the left, a 'Proximity LAN' connects to a 'MEX Communications and Computing' system, which is further connected to 'Agents Asset Cops' and an 'EVA Rover'. The 'Explorers/Scientists' also interacts with 'Digital Camera', 'Video Camera', and 'Hand-held Instruments'. These inputs feed into a 'Hosted Control' block, which also receives 'Commanded Path (opt. Inertial display)'. The 'Hosted Control' outputs 'Speech Input', 'Speech Output', and 'Per Input' to a 'REALIST Speech Recognition' block, which provides 'Audio Input (opt. Inertial)' and 'Audio Output (opt. Inertial)'.

## Mobile Agents

Integrated simulations of human-robotic exploration, motivated in part by field research at the Flashline Mars Arctic Research Station, have highlighted requirements for natural language interaction among humans and robots. Such interactions would enable advanced capabilities ranging from simple direct commands to AI systems that monitor mission status by “intelligent listening” to party-line discussions.



Future NASA missions require improved methods of human-computer interaction based on spoken natural language dialogues. To address this need, NASA has formed a new research initiative in spoken dialogue natural language interfaces as part of its program in human-centered systems. Under this initiative, technologies for such interfaces will be developed and exploited, including robust speech recognition, language models and grammars, and dialogue-based user interfaces. These technologies will be applied to a variety of NASA missions and applications, including science data management, mission operations, airport ground movement and semi-autonomous robotic agents.

There are many different types of agents being developed by NASA giving a rich variety of possibilities for experimentation. The research builds on extending established speech and language technology such as the Nuance recognizer and the SRI Gemini and Open Agent Architecture systems.

The current research focuses on contextual interpretation, portability, asynchronous dialogue management, and natural dialogue designs. Future research topics include dynamic-synapse methods for recognition enhancement, prosody focus for system spoken output, dialogue move based dialogue management, language modeling based on sparse training data, rational integration of multiple knowledge sources, and evaluation of confirmation methods for collaborative dialogues.



# Products: Multimodal Interfaces

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Lifecycle Support for Collaborative Science

<http://www.acm.org/cscw2000/progworkshops.html#w7>

ScienceOrganizer

Registered users: 55

Projects/workgroups: 5

NSF grant to Arizona State, microbial diversity

Symposium on Computational Discovery of Communicable Knowledge

Stanford University, March 24 - 28, 2001

<http://www.isle.org/symposia/comsched.html>

George, S., Dibazar, A., Liaw, J.S., and Berger, T.W. Speaker Recognition using Dynamic Synapse Based Neural Networks with Wavelet Preprocessing. *Proceedings of the IEEE International Joint Conference on Neural Networks*, 2001, 2, 1122.

Namarvar, H., Liaw, J.S., Berger, T.W. A New Dynamic Synapse Neural Network for Speech Recognition. *Proceedings of the IEEE International Joint Conference on Neural Networks*, 2001, 4, 2986 - 2990. (IEEE IJCNN Best Presentation Award, 2001)



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# Human-System Modeling

Title	Org.	PI
Work Systems Modeling and Simulation (Brahms)	RIACS	Sierhuis
Human-Automation Integration	ARC	Lowry
Models of Learning in Complex Dynamic Tasks	CMU	Anderson
Human-Robotic Teams	IHMC	Bradshaw
Human-Centered Software Development	MIT	Leveson
Model Usability	CMU	John

As mentioned above, life-cycle costs and risks are mitigated when human behavior can be included in early design-related models. The objective is to improve the early decisions made in the design of mission systems and to enable designers to incorporate cost-effective models of human behavior, procedural tasks, human-automation interaction, time-budgets for individual agents, and consistency-checks on synchronous and asynchronous (e.g., document-mediated) communication.

The aim of this research is to understand how people and systems are interconnected in practice. To accomplish this, research focuses on work systems analysis and evaluation, and on computational models for simulating how people interact with automated systems. The technical approach is based on the view that Human Centered Computing is a software engineering methodology. This methodology is based on the scientific study of cognition in people and machines, especially understanding the differences between perceptual-motor, cognitive, and social aspects of people and present-day computers. The commitment to HCS as a software engineering methodology also implies that HCS should be integrated with other advanced software engineering methodologies. This implication is explicitly addressed in the projects led by Mike Lowry, Jeff Bradshaw, and Nancy Leveson.

**hygiene**



**eating**



**read daily activities**



**check calibration**

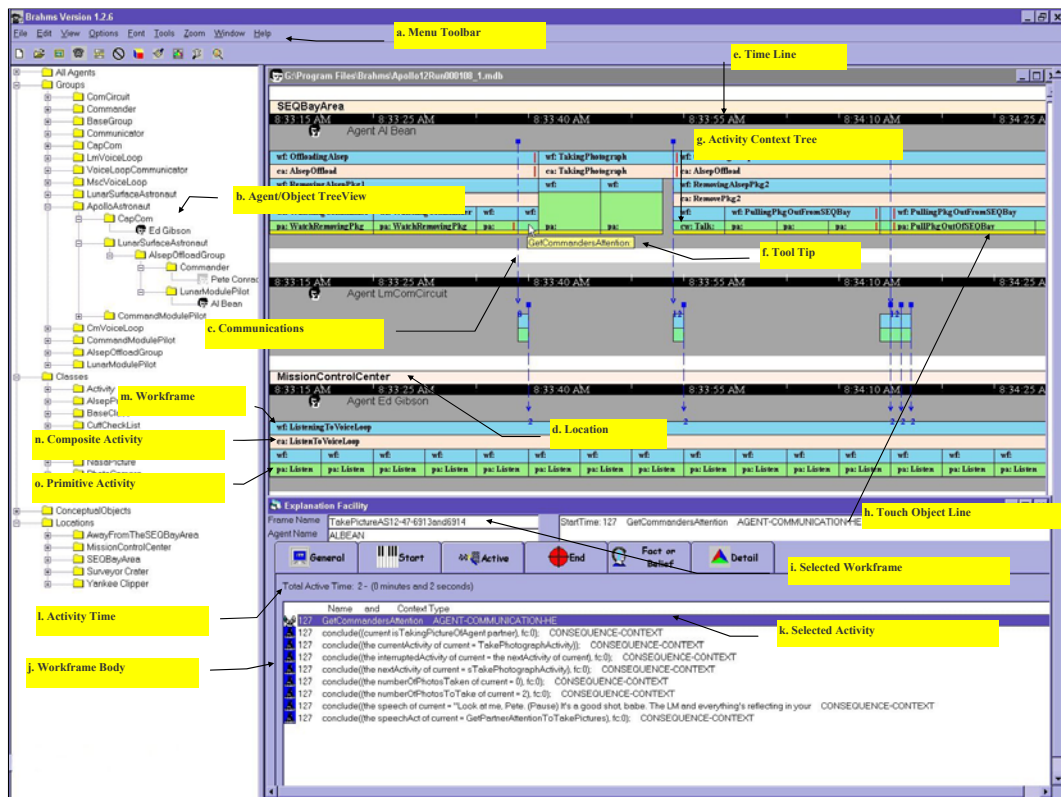


**exercise**



**communicate**

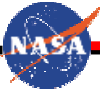




The preceding viewgraph illustrates some of the kinds of activities that must be accounted for in the individual time-budget of every crew member on the International Space Station. Since this set of activities is heterogeneous, abstract task-function models can err significantly in estimating manageable workload.

This is a screen shot of the Brahms Agent Viewer. The results of Brahms simulations can be used as a practical aid to early mission planning. Early prototype procedures can be checked across multi-person teams to identify problems related to time-budgets within individuals and communication disconnects between individuals. A number of Brahms applications have been documented, and work is currently underway with ISS and MER.

Another important point about Brahms is that its computational foundation is highly compatible with the formal methods used by Lowry, Bradshaw, and Leveson. Therefore, Brahms is particularly good at representing crew behavior in a form that can be integrated with system-modeling and software V&V tools.



# Brahms Modeling

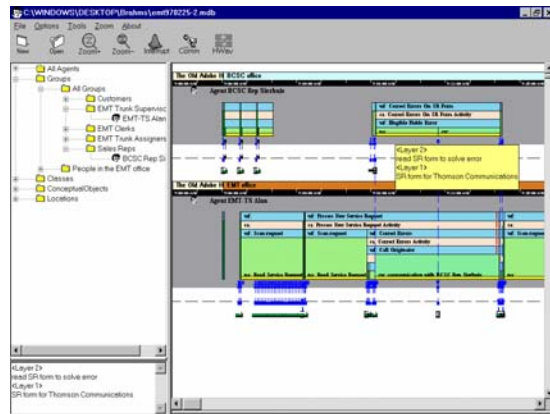
Visualize and evaluate operational models early in the design process

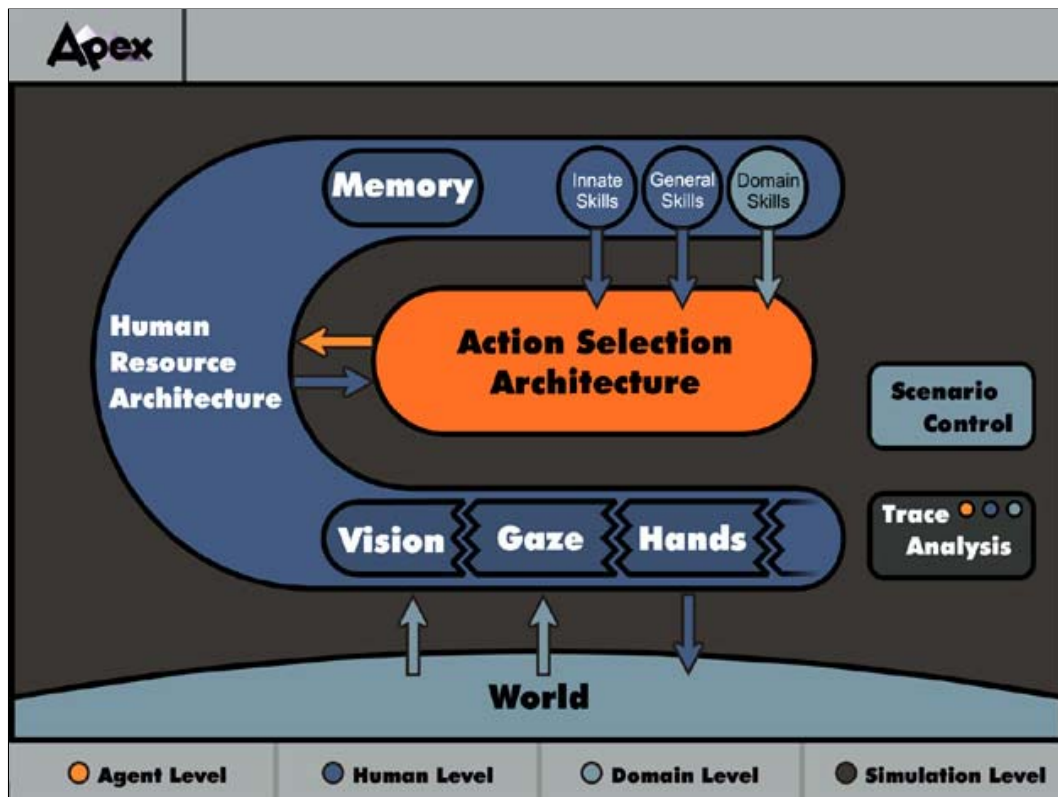
## Modeling Benefits

- Visualize new operations & maintenance concepts
- Estimate value-added of automation
- Identify C<sup>3</sup> bottlenecks and risks
- Design intelligent training systems
- Improve scheduling of key resources
- Estimate of human factors requirements in early design

## Modeling Capabilities

- Patented, industry-tested modeling approach
- Multi-agent programming language
- Integrated modeling support tools
- Standard COTS h/w and s/w compatible
- Visualization of inter-agent communication
- Simulation of time- and resource-requirements
- Automatic workflow diagrams





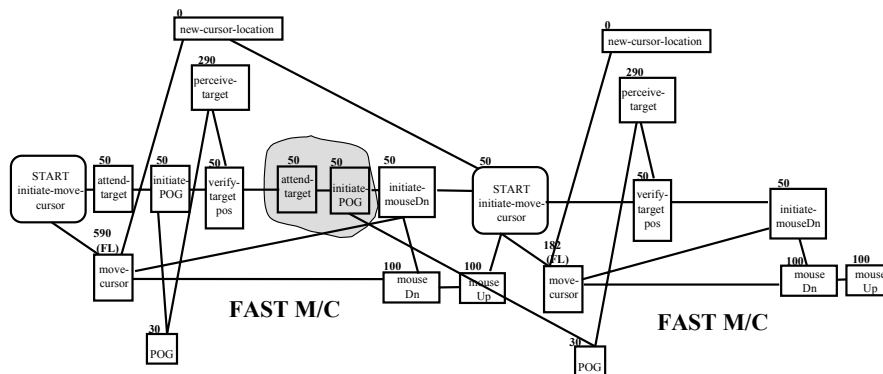
The Apex architecture is similar to systems like MIDAS and Epic-Soar. See R.W.. Pew & A.S. Mavor (Eds.). (1998). *Modeling human and organizational behavior: Application to military simulations*. Washington, DC: National Academy Press.

Apex is capable of modeling complex human performance and also of serving as an intelligent control system (stand-alone AI system).

One of the key technologies incorporated in Apex is the Reactive Planning concept developed by James Firby (RAP). Reactive Planning has also been independently identified as a core technology in other HCS projects, such as the work of Debra Schreckenghost under Decision Systems.



## Apex-GOMS Analysis of Procedures



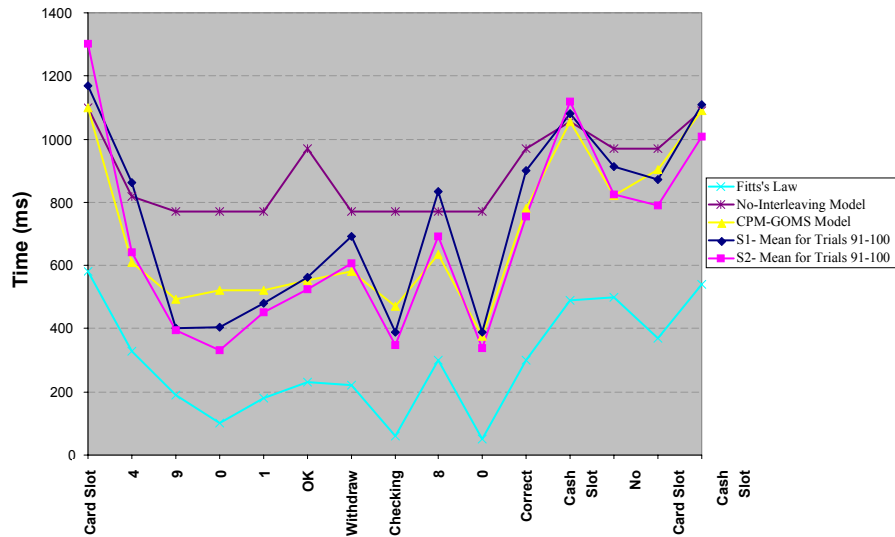
Another well-known human modeling approach is the Goals, Operators, Methods, and Selection-rules (GOMS) method published by Card, Moran, and Newell in 1983. GOMS, like John Anderson's ACT-R, has been extensively applied and refined in real-world analyses.

See <http://www-2.cs.cmu.edu/afs/cs/user/bej/www/GOMS.html>

HCS has co-funded, along with NASA's Airspace Operations Systems Base R&T Program, the work illustrated here: Through an application and extension of the Apex modeling framework discussed above, a major step was taken in the automation of GOMS analyses, reducing by about two orders of magnitude the time to model a typical task. This work was conducted by Mike Freed and Alonso Vera (SJSU), Bonnie John and her students (CMU HCI Institute), and Roger Remington and Mike Matessa (NASA Ames).

Several publications on this accomplishment are cited in the "Products" page below.

# Apex-GOMS and Human Performance Data



These data illustrate how much better the improved Apex-GOMS model fits the data from two individual subjects. Comparison is with the unimproved GOMS model and with an older standard Human Factors analysis based on Fitts Law.

The improved Apex-GOMS model provides substantially better fit to individual subjects' data than either of the alternatives.

Not every task in every system needs to be modeled at this level of detail. Such accurate modeling is cost-effective, for example, when highly practiced, safety-critical procedures are being analyzed, and especially when it is necessary to evaluate possible changes to those procedures.



# Products: Human-System Modeling

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Brahms patent award, April, 2001

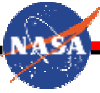
- Sierhuis, M. (2001). *Modeling and simulating work practice. BRAHMS: A multiagent modeling and simulation language for work systems analysis and design*. Amsterdam, The Netherlands: Social Science and Informatics Department, University of Amsterdam.
- Apex Tutorial, Cognitive Science Conference, August, 2001
- Simulating Human Agents AAAI Fall Symposium, Michael Freed, Chair  
[http://www.aaai.org/Press/Reports/Symposia/Fall/fs\\_00\\_08.html](http://www.aaai.org/Press/Reports/Symposia/Fall/fs_00_08.html)
- Human Interaction with Autonomous Systems in Complex Environments  
2003 AAAI Spring Symposium proposal accepted  
David Kortenkamp, Mike Freed (co chairs)
- Leveson, N.G., Allen, P., & Storey, M. (2002). The Analysis of a Friendly Fire Accident Using a Systems Model of Accidents. *20th International System Safety Conference*, Denver, CO.
- Matessa, M., Vera, A. H., John, B., Remington, R., and Freed, M. (2002) Reusable templates in human performance modeling. *Proceedings of the Twenty Fourth Conference of the Cognitive Science Society*. Fairfax, VA.
- John, B. E., Vera, A. H., Matessa, M., Freed, M., and Remington, R. (2002) Automating CPM GOMS. In *Proceedings of CHI'02: Conference on Human Factors in Computing Systems*. ACM, New York.
- Matessa, M. (2001). The benefit of structured interfaces in collaborative communication. In *Working Notes of the 2001 AAAI Fall Symposium on Intent Inference for Collaborative Tasks*. AAAI Press.
- Vera, A. H. & Kvan, T. (2001). Performance and Learning in Collaborative Problem Solving. In *Proceedings of AAAI '01 Fall Symposium*. ACM: New York.



# Outline

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- **Motivation**
- **Strategic Approach**
- **Selected Projects and Products**
  - **Multimodal Interface Technology**
    - Collaborative Science
    - Dialogue Systems
    - Products
  - **Human-System Modeling**
    - Brahms
    - Apex-GOMS
    - Products
  - **Agent-Based Decision Systems**
    - Mars Exploration HCS Tasks
    - Intelligent Launch and Range Operations
    - Integrated Mission Operations for ISS
- **Opportunities**



## Decision Systems

Title	Org.	PI
Mars Exploration HCS Projects	ARC	Trimble, Schreiner
Intelligent Launch and Range Operations	ARC, CMU	Remington, Bardina, John
Mobile Agents	ARC	Clancey
Habitat Design and Scheduling	ARC	Clancey
Human-Centered Advisory and Assistant Systems for Mission Control	JSC	Malin
Distributed Control of Life-Support Systems	Metrica	Schreckenghost
Human-Centered Flight Surgeon Console	UTHMC	Zhang

The HCS projects in this sub-element all focus on high-priority NASA missions: ISS ground and on-board operations for information management, biomedical monitoring, power management, and life support; launch and range operations; and distributed and remote science operations.



# Mars Science Portal Content

Search: Sol 13 & Target 5

Results:  
[Gemini Scuff TES](#)  
[MER B uplink plan](#)  
[SOWG Meeting Minutes 041504](#)  
[Gemini Navcam image pair](#)

Science Managers Portal

All-Hands meeting 10:00 AM PST (Seq Team Excepted)  
MER B Landing Site Official Release  
Shift Change begins Saturday 04/02/04  
Solar Panel Performance Update  
Daily Coordination Briefings schedule change  
MER A Comm Link diagnosis underway – ETC 15:47

MET 30d 14h 13m

Downlink DTE/UHF 03:13/03:25

SOWG 2:47

Uplink 17:24

Miss. Mgr MOS Ops GDS NAV Science Email Whiteboard

ext Update..... Press Briefing at 0745 PST – All Science products for release

Resource Predicts	MER A	MER B
Energy Available W/hr	686	691
Downlink Data Volume (Mbits)	12.8	12.8
Rover Time Available (Hrs)	3	3
UHF Downlink Data Vol. (Mbits)	51.9	NA
Success Criteria	MER A	MER B
Locations (B)	2	3
Panoramas/Targets (1/3)	4/26	4/26

Comm-link Performance (Mbits)

Project Technical Approach and Planning Files, Sunday, 22 Apr 2001 11:21

[Folder browser](#) Project Technical Ap... Go Mode View Ds Sort by Sequence

[Link to 4 year budget estimate \(01-04\)](#), Sunday, 22 Apr 2001 11:21

[Schreiner, John A](#) Link to 4-year budget estimate (01-04)

[Supporting Slides - Section K](#), Tuesday, 21 Apr 2001 20:38

[OCIS Security - Release 041701](#)

[Supporting Slides - Section J](#), Tuesday, 21 Apr 2001 20:38

[OCIS Integrated Schedule Overview - Release 041801](#)

[Supporting Slides - Section I](#), Tuesday, 21 Apr 2001 14:47

[Schreiner, John A](#) Interview Questions working slides used during concept development

[Supporting Slides - Section H](#), Tuesday, 21 Apr 2001 14:38

The Mars Exploration Rovers (MER) Science Team will focus on immediate task performance and data searches:

1. What is the health and state of the rovers ?
2. What shifts are on today ?
  - Who is Science Operations Working Group Chair of team #2
3. When is the next uplink ?
  - Does a sequence plan exist yet ? – if so show it to me.
  - Why are they returning to the same site ? – show me the justification
4. What and when is the next major event ?
5. Where are the rover support groups in their process of preparation for the next event ?
  - What is the ETC for the SOWG meeting ?
  - Where is it being held
6. What were the most recent discoveries or significant findings ?
  - Show me the data
  - Who produced this result ?
  - Where is this person now, where are they from, and what is their phone number ?
7. When is the next major milestone ?
8. I want to post a message to the team

# Mars Operations Portal Content



Sol 43 aft quadrant

### MER Operations Portal

[All-Hands meeting 10:00 AM PST \(Seq Team Excepted\)](#)  
[MER B Landing Site Official Release](#)  
[Shift Change begins Saturday 04/02/04](#)  
[Solar Panel Performance Update](#)  
[Daily Coordination Briefings schedule change](#)  
[MER A Comm Link diagnosis underway – ETC 15:47](#)

MET **42d 14h 13m**

Downlink DTE/UHF **03:13/03:25**

MERA ETS **02:47**

Uplink **17:24**

Miss. Mgr
MOS
Ops
GDS
NAV
Science
Email
Whiteboard

**ext Update.....**

Resource Predicts	MER A	MER B
Energy Available W/hr	686	691
Downlink Data Volume (Mbits)	12.8	12.8
Rover Time Available (hrs)	3	3
UHF Downlink Data Vol. (Mbits)	51.9	NA

Success Criteria	MER A	MER B
Locations (8)	2	3
Panoramas/Targets (1/3)	4/26	4/26

Range estimate is now 5.31 m, change from 5.23m

Probable obstacle from Sol 35  
No – that rock is too small

**Total Traverse**

**MER Ops Instant Messenger Board**

Andy> We're still waiting for the SOWG to complete their request doc

Brian> Can't we get going with the template file ?

Andy> I need the latest version – do you have it ?

Brian> Check version 3B, over on docshare, or search templates under my name. We should have a standard location for these and get version control too.

Andy> I'll add that to the agenda for the next coordination meeting

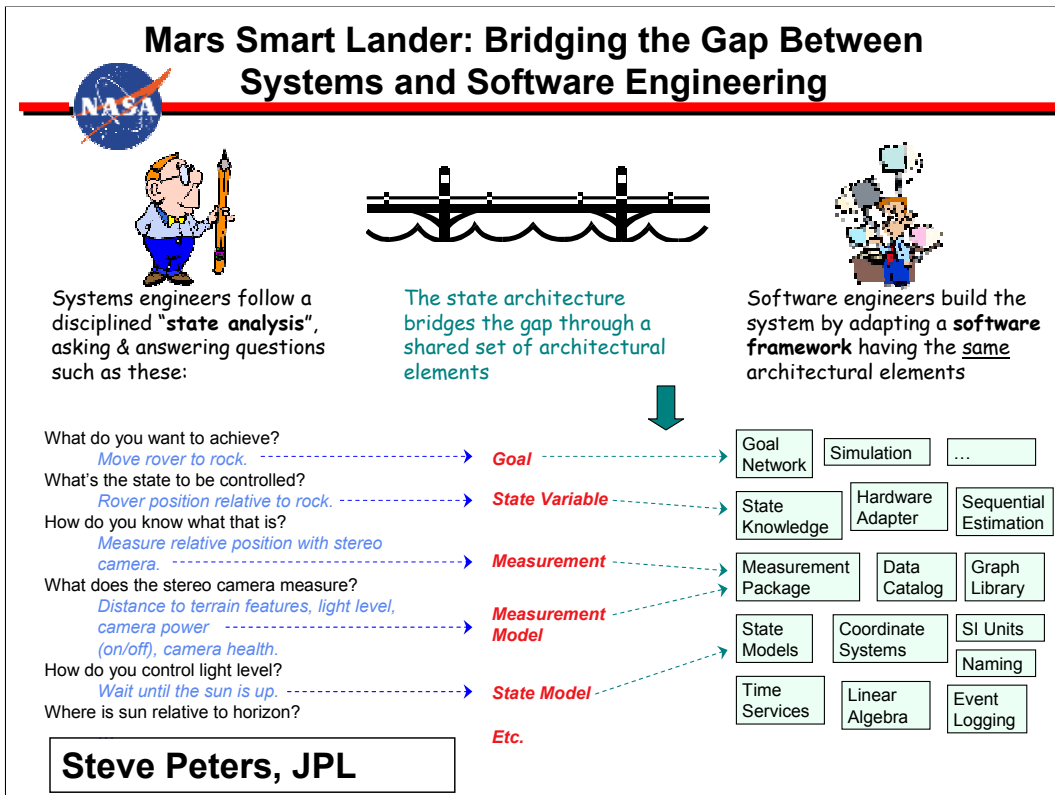
Mark> I have a copy – I just put it on the desktop for you

Andy> Thanks

**MER Operations focus on immediate task performance.**

**Ensuring milestones are met:**

1. What is the health and state of the rovers ?
2. What shifts are on today ?
  - Who is SOWG Chair of team #2
3. When is the next uplink ?
  - Does a sequence plan exist yet ? – if so show it to me.
  - Why are they returning to the same site ? – show me the justification
4. What and when is the next major event ?
5. Where are the rover support groups in their process of preparation for the next event ?
  - What is the Estimated Time of Completion for the SOWG meeting ?
  - Where is it being held?
6. What were the most recent discoveries or significant findings ?
  - Show me the data
  - Who produced this result ?
  - Where is this person now, where are they from, and what is their phone number ?
7. When is the next major milestone ?
8. I want to post a message to the team



The Mars Smart Lander (MSL) or Mars'09 Mission aims to use an innovative approach to system engineering and software engineering, as illustrated here. The resulting Mission Data System (MDS) will be much more capable of supporting advanced autonomy.

MDS will have broad-ranging impacts on mission operations. This provides an important set of HCS research challenges in two major areas: human-automation integration and distributed science operations.

We believe that our current HCS portfolio has positioned us well to meet these challenges. We have mature projects that address distributed scientific collaboration, complex human-automation behavioral modeling, and information integration to support Mars exploration missions in particular. Nevertheless, developing a flexible and credible set of modeled operations concepts, covering the plausible range of mission scenarios and autonomy capabilities, will be a stringent test of HCS methods and technologies.



## **Mars Smart Lander: Operations Design Assumptions**

---

- **New flight system technology, high levels of autonomy, long duration, fast-paced science mission**
- **Ground Data System (GDS)**
  - **Enable reliable goal definition, elaboration and scheduling of desired science activities**
  - **New or adapted planning tools for test and training exercises and for flight operations**
  - **Extensive testbed validation of planning tools and products**

**Nino Lopez, JPL**

Among other things, HCS research should be able to help JPL mission planners develop detailed operations concepts and procedures for human interaction with autonomous flight systems, where the degree of capability of the autonomous system may vary from current (low) levels to high levels, and the specific capabilities may depend on the outcome of future development and testing.

HCS analyses will be able to contribute to the planning, execution, and evaluation of test and training exercises.

HCS distributed science technologies should be able to provide prototype candidate tools and products, as well as systematic, quantitative evaluation methods for subsystems that include expert decision-makers, controllers, and planners. Human-system modeling tools should be able to support a range of testbed activities, from low-cost approximate analyses to carefully planned and focused field tests.

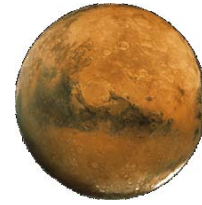
# Launch & Range Technology: On Many Critical Paths



**Developing and Improving Systems**



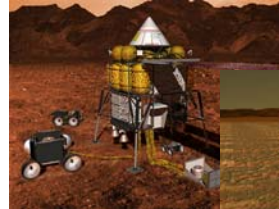
**Living & Working in Space**



**Exploring the Universe**



**Developing new vehicles**



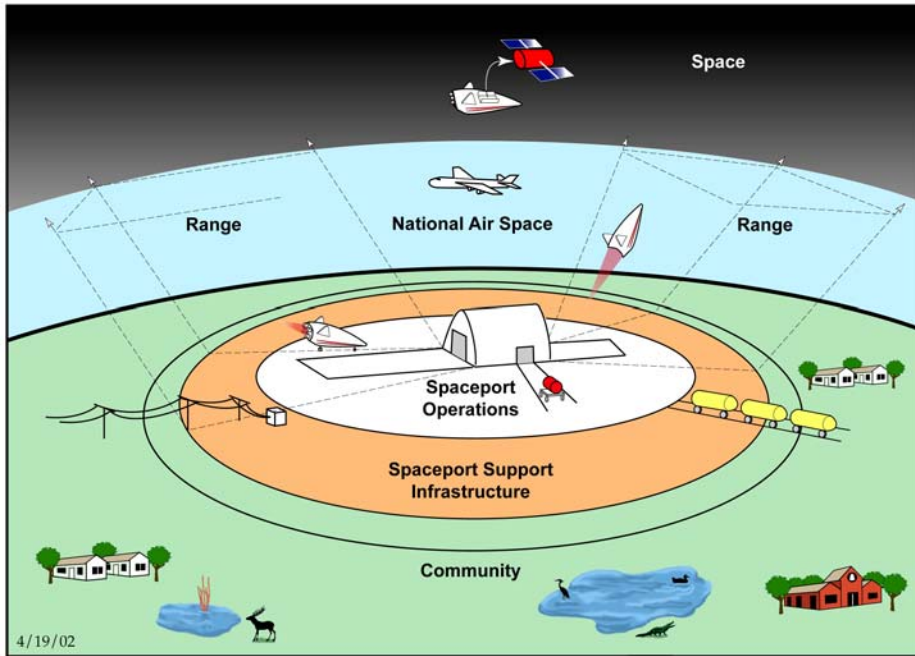
**Going to Mars**

No technology is more important to NASA than cost-effective launch and range operations. The term *Spaceport Technology* conveys the vision of space transportation infrastructures that operate as safely and as cost-effectively as *airports*.

Spaceport Operations technology is on the critical path of every NASA mission – International Space Station, Space Launch Initiative, human and robotic science missions.

In coordination with the Advanced Spaceport Technology and Advanced Range Technology Working Groups, ASTWG and ARTWG, HCS researchers are making a focused contribution to modeling and evaluating those aspects of advanced operations concepts that involve human experts in critical decision making roles.

# Spaceport Environment

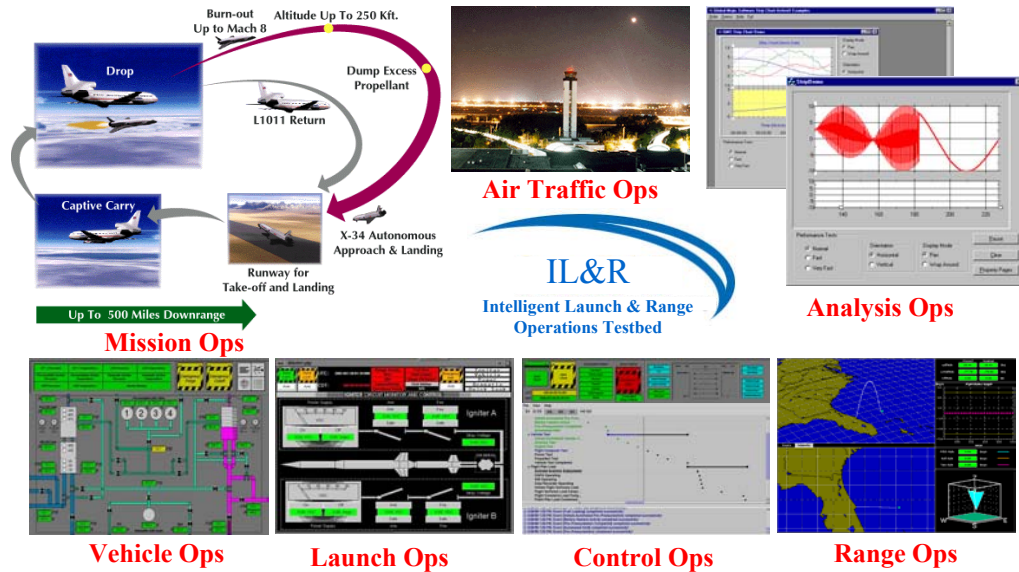


Human operators have traditionally been responsible for overall system safety. They are required to monitor, assess, and evaluate numerous system parameters, as well as relations among heterogeneous parameter-sets and launch-commit criteria.

In the future, a significant increase in autonomous systems will be required to achieve aggressive performance and cost-effectiveness goals. Human experts will continue to play significant, safety-critical decision making roles even in a highly automated spaceport/range system.

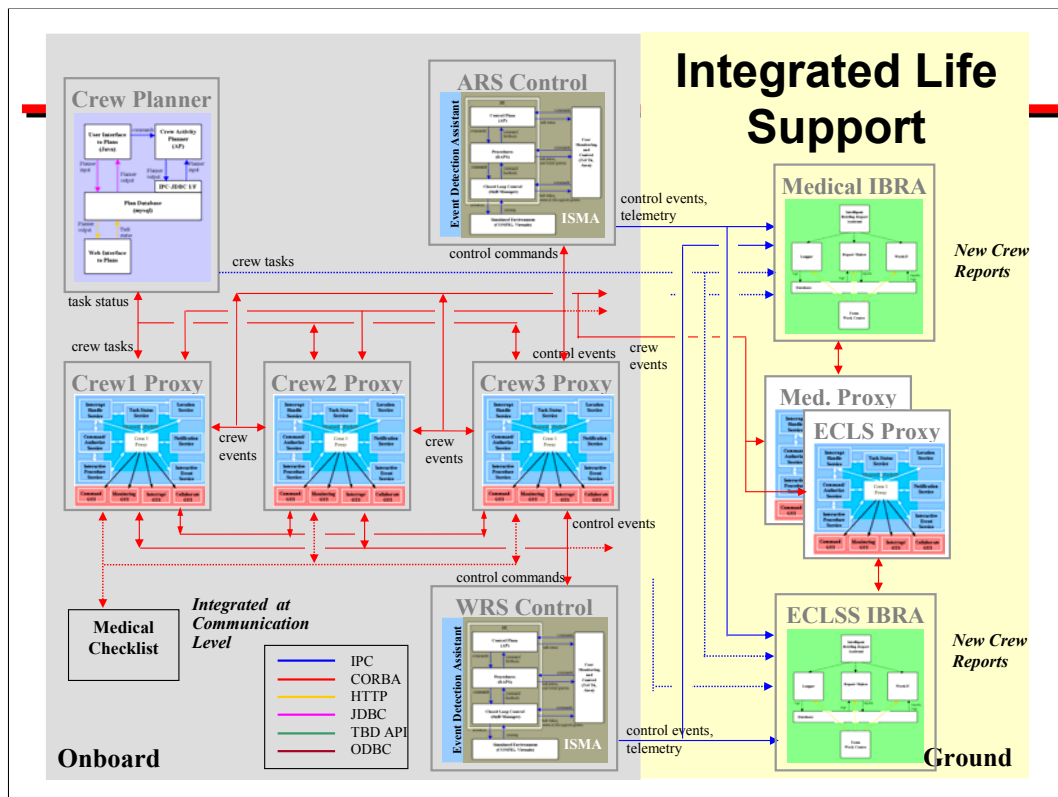
Factors that have to be balanced in the overall decision making process include crew safety, community safety, environmental protection, weather predictions, National Airspace System safety and security, military airspace and launch constraints, and complex constraints based on mission windows-of-opportunity, orbits of other spacecraft, etc.

# Intelligent Launch & Range Operations



This viewgraph pictures some of the critical technical and operational functions that must be smoothly integrated in future launch and range operations. The HCS objective is to reflect all these functions in the ILRO testbed, and to provide the capability to evaluate operations concepts with humans in the loop and with human-behavior models in the loop.

NASA research on Air Traffic Management and Aviation Safety has already demonstrated some capability to integrate human decision makers and (limited) human operator models in a dynamic scenario. ILRO hopes to extend this capability to the domain of future launch and range operations.



A proposed FY03 demonstration at JSC will integrate information-management and system monitoring agents, proxies for crew and ground controllers, and automated software agents for life support control and crew activity planning. These technologies are being developed and tested individually in three different HCS projects at JSC, with additional funding from Code M and other sources.

The demonstration scenario will illustrate nominal operations across multiple systems (life support and medical), anticipated off-nominal operations requiring trained response, and unanticipated off-nominal operations requiring novel response and teaming of crew and ground support.

Integration of crew-activity oriented agents with system-monitoring and information-management agents will provide the following capabilities:

- Event/report notification based on roles, organizational policies, user preferences, and user location
- Shift assignment using task status service
- Location tracking using location service

Integration of system-monitoring and information-management agents with Ground Proxies will enable the following services:

- Ground Proxies are informed when a report has been generated
- Ground Proxies determine whom to notify and how (timing, modality)
- User edits the report instruction; the scope of the change constrained by role and organizational policies

Integration of the Sapiens System medical checklist with Crew Proxies will enable the following:

- Monitor crew interaction with checklist to determine state of procedure execution
- Mark medical task complete in Proxy when complete checklist

Integration of automated life-support system monitoring with system-monitoring and information-management agents will enable these functions:

- Life Support Proxy informs Biomedical Engineering Ground Proxy when automated life-support performs tasks affecting medical status (e.g., notify anomaly team members of team activities)
- Crew Proxies inform Ground Proxies of important crew activities

Integration will make available new sources of information for automated ground reports:

- Crew schedules from Crew Activity Planner
- Crew Update Events (activities, location, and roles) from Crew Proxies
- Control Events from Life Support Event Detection



# Products: Decision Systems

- Mars Desert Research Station (MDRS) Field Test, April, 2002  
<http://www.marssociety.org/MDRS/2002Dispatches/index.asp>
- Clancey, W. J. 2001. Field science ethnography: Methods for systematic observation on an arctic expedition. *Field Methods*, 13(3):223-243.
- Clancey, W. J. 2000. Visualizing practical knowledge: The Haughton Mars Project. (Das Haughton Mars Projekt der NASA — Ein Beispiel für die Visualisierung Praktischen Wissens). In Christa Maar, Ernst Pöppel and Hans Ulrich Obrist (Eds.), *Weltwissen - Wissenswelt. Das globale Netz von Text und Bild*, pp. 325-341. Cologne: Dumont Verlag. (Presented at the 3rd Millennium Conference on Knowledge and Visualization, Munich, February, 1999.)
- Clancey, W. J., Lee, P., and Sierhuis, M. 2001. Empirical requirements analysis for Mars surface operations using the Flashline Mars Arctic Research Station. *FLAIRS-2002 Proceedings*, Key West, FL, pp. 24-26.
- Clancey, W. J. (in press). Simulating "Mars on Earth"—A report from FMARS phase 2. *Proceedings of the Mars Society Annual Meeting*, Stanford, CA, August 2001.
- Malin, J. T., Johnson, K., Molin, A., Thronesbery, C. and Schreckenghost, D. "Integrated Tools for Mission Operations Teams and Software Agents." To appear in *2002 IEEE Aerospace Conference Proceedings*, Big Sky, Montana, March, 2002.
- Malin, J. T. "Information Handling is the Problem." Presentation on Panel, Help and Hindrance: Impact of Automation on Experts Collaborating in High Stakes Settings. 2001 American Medical Informatics Association Annual Symposium, Washington, DC, Nov., 2001.



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- **Motivation**
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    - Products
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    - Brahms
    - Apex-GOMS
    - Products
  - **Agent-Based Decision Systems**
    - Mars Exploration Rovers HCS Tasks
    - Intelligent Launch and Range Operations
    - Integrated Mission Operations for ISS
- **Opportunities**



## **Related Research**

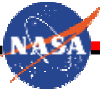
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### **NASA and multi-agency programs with HCS content**

**Airspace Operations Systems  
CICT Program  
Aero Capacity Program  
Engineering for Complex Systems  
International Space Station  
Space Launch Initiative  
Exploration Missions  
Aviation Safety and Security Programs (w/FAA)  
Computer Generated Forces & Behavior Representation (w/DOD)  
HCI & Information Management Working Group (w/NSF et al.)  
Advanced Range Technology Working Group (w/FAA, USAF)  
Advanced Spaceport Technology Working Group**

NASA's HCS R&D encourages participation by PI's and mission operations personnel in workshops and reviews, joint participation in professional meetings, and participatory design that directly involves colleagues at other NASA Centers.

We depend on constructive interaction with other NASA R&D programs, as well as with programs sponsored by DARPA, NSF, ONR, DOE, and other agencies.



## HCS Management Process

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- **Publications and presentations**
- **Collaboration with NASA missions**
- **Review Meetings**
  - Two per year
    - 1 at a NASA Center
    - 1 at a university
- **Focused Workshops**
  - Simulating Human Agents (AAAI Fall 2000)
  - Apex Tutorial (Cognitive Science Fall 2001)
  - Discovery (pre-AAAI Spring 2001)
  - Causal Reasoning (TBD)
  - Natural Language Technologies (TBD)
  - Mission System Design & Evaluation (TBD)
- **Site Visits**

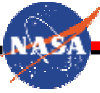
In addition to our own program reviews (twice a year) we aim to support focused, PI-led workshops on topics of special interest. Ideally, such workshops would be coordinated with major conferences, such as AAAI or Cognitive Science, or implemented through existing venues like the Fall and Spring Symposia, the CGF&BR Conferences, IJCAI, FLAIRS, IEEE/SMC, HFES, SIGCHI.



## Integrate, Test, Transfer

Project	Integrates, tests, and transfers technology from:
Mars Exploration HCS Projects	Brahms, Apex-GOMS, Concept Maps, ScienceOrganizer, Human-automation integration
Launch & Range	Apex-GOMS
Mobile Agents	Brahms, KaOS, Dialogue systems
Habitat scheduling	Brahms, Concept Maps
ISS Mission Operations	Brahms, Apex, ACT-R, Hybrid-system design, Dialogue systems, Causal reasoning

The more complex Decision Systems projects can draw upon technologies that are prototyped and tested under Multimodal Interfaces and Human-System Modeling. Although it is not always feasible, HCS encourages individual PI's to become involved in projects that span different levels of technology maturity. Obviously, this approach aims to infuse HCS methods and technologies into NASA work practices, but just as often involvement in concrete mission activities generates ideas for innovative research.



## Source Summary -- Universities

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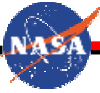
- **Institutions (PI and collaborators)**
  - **Massachusetts Institute of Technology**
  - **Carnegie Mellon University**
  - **Brown University**
  - **Princeton University**
  - **Institute for Human and Machine Cognition**
  - **University of Southern California**
  - **Research Institute for Advanced Computer Science**
  - **Wright State University**
  - **University of Illinois**
  - **Purdue University**
  - **Georgia Institute of Technology**
  - **University of Central Florida**
  - **Embry Riddle Aeronautical University**
  - **San Jose State University**
  - **Stanford University**
  - **University of Texas**
  - **University of California – San Diego**
  - **UCLA**



## Source Summary -- Other

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- Institutions (PI and collaborators)
  - NASA- Ames
  - NASA- Marshall
  - NASA- Johnson
  - NASA- Kennedy
  - NASA- Goddard
  - Jet Propulsion Laboratory
  - Boeing
  - SETI Institute
  - SAIC
  - SRI International
  - Kestrel Technology
  - Bolt Beranek & Newman
  - Sarnoff Corporation
  - Raytheon
  - WYLE Laboratories
  - ISLE
  - Digital Space
  - Intelligent Automation
  - Optimal Synthesis
  - Command and Control Technologies



## **Reviewers – University Affiliations**

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**University of Michigan**  
**Ohio State University**  
**University of Illinois**  
**University of Illinois -- Chicago**  
**University of Massachusetts**  
**Carnegie Mellon University**  
**University of Pittsburgh**  
**Georgia Tech**  
**University of Central Florida**  
**Mississippi State University**  
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**University of California – San Diego**  
**University of California – Santa Barbara**  
**San Jose State University**  
**Stanford University**  
**University of Oregon**



## **Reviewers – Industry & Government**

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**Intel Corporation**  
**Rand Corporation**  
**NEC Research Institute**  
**Research Integrations**  
**Department of Energy**  
**National Science Foundation**  
**Office of Naval Research**  
**Naval Air Weapons Center**  
**National Science Foundation**  
**DARPA**  
**NASA**



## Leveraged Funding By Source

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- **DARPA \$12.8M**
- **NSF \$9.1M**
- **AFOSR, AFRL \$2.8M**
- **ONR, NAWC-TSD \$2.3M**
- **NIH \$1.4M**
- **FAA \$0.5M**
- **Other public sector \$0.5M**
- **Private sector \$4.3M**
- **TOTAL \$33.7M**
  - (1:1, conservative estimate for FY01-FY03)